Gamma radiation induced changes in the optical properties of CdTe thin films for dosimetric purposes

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Abstract

The effect of 0.662MeV gamma radiation on the optical properties of the CdTe thin films was studied. 300nm thickness of CdTe samples were irradiated with doses (10, 20, 30,60krad) in room temperature. The absorption spectra for all the samples were recorded using UV-Visible spectrometer in order to calculate the energy gap, width of localized states and optical constants(refractive index, extinction coefficient, real and imaginary parts of dielectric constant). The optical energy gap was found to decrease from (1.53 to 1.48 eV), while the width of localized states increased from (1.34 to 1.49 eV) with the increasing of radiation dose. The behavior of energy gap with the irradiation dose makes the material a good candidate for dosimetry in industrial applications.

Key words
CdTe thin films, optical properties, gamma radiation effect.

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اشعاع كاما يحث تغيرات في الخواص البصرية للاغشية الرقيقةCdTe لاغراض تحسس الجرع الاشعاعية

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الخلاصة

تمت دراسة تأثير أشعة كاما ذي طاقة 0.662 MeV على الخواص البصرية للغشاء الرقيق CdTe، حيث شععت نماذج الاغشية الرقيقة بسمك 300 nm مع جرع اشعاعية (10، 20، 30، 60 krad) في درجة حرارة الغرفة. وتم قياس أطياف الأمتصاص لجميع النماذج باستخدام المطياف البصري في مدى الاشعة الفوق بنفسجية- المرئي وذلك لحساب فجوة الطاقة البصرية وعرض الذيول والثوابت البصرية. ووجد بان فجوة الطاقة تقل من (1.48-1.53eV) وعرض الذيول يزداد من (1.49-1.34eV) مع زيادة الجرعة الاشعاعية. ان تصرف فجوة الطاقة مع الجرع الاشعاعية يبين بان الغشاء الرقيق المستخدم متحسس جيد للجرع وخاصة في التطبيقات الصناعية.

Introduction

Cadmium telluride (CdTe) is a crystalline compound formed from cadmium and tellurium. It is a member of the II-VI family of compound semiconductors which shows unique properties making it important and very suitable for several applications. CdTe band gap about 1.5eV, just in the middle of the solar spectrum, and possess high absorption coefficient (α) ($>10^4 cm^{-1}$) for the visible solar spectrum [1]. It has cubic zincblende lattice structure which belongs to the tetrahedral phases; that is, each atom is surrounded by four equidistant nearest neighbors which lie at the corners of a tetrahedron [2].

CdTe is a direct band gap semiconductor which means that the maximum in the valence band (E_v) and the minimum in the conduction band (E_c) occur at the same momentum. Thus, transitions of electrons mostly occur between two bands of the same wave vector (i.e., $\Delta k=0$) , where the electrons move from the top of the valence band to the bottom of the conduction band , and vice versa, by absorbing or emitting a photon without involving any phonon interaction. The photon energy must be greater than or equal to E_c-E_v [3].

Irradiation with gamma rays changes the physical properties of the materials which they penetrate. The changes are strongly dependent on the internal structure of the absorbed substances. It is believed that ionizing radiation causes structural defects leading to their density change on the exposure to γ-rays [4].

The general types of radiation effects on materials can be categorized into:

(1) Atom displacement from their normal position in the structure of the material; displacement atoms may leave lattice vacancies and lodge in interstitial locations or cause interchange of dissimilar atoms in the lattice structure.

(2) Ionization, that is, the removal of electrons from atoms in the material and the formation of ion pairs in the path of the charged particles. Since gamma radiation interacts with matter in several ways depending on radiation energy, such as, photoelectric effect and compton scattering[5].

The effects of radiation on semiconductor, which have small forbidden energy, gap between the valence and conduction band, its produces a large number of excited atoms along its track. After the traversal of the radiation, vacancies may be left in the valence band and there will be some electrons in the conduction band. Since the direct recombination of the conduction band electron with the vacancy is a highly forbidden process, the electron is free to drift through the material. Thus, this irradiation event has created electron-hole pairs an electron in the conduction band and a hole in the valence band.

The influence of gamma radiation onto different types of thin films has been discussed [6, 7]. The intention of this study is to investigate the effect of irradiation on optical properties of CdTe thin films.

Optical properties

Optical absorption analysis has widely proven to be an important and efficient tool in exploring and interpreting the various phenomena of electronic structures and processes in the materials subjected to radiation [8, 9], so as the importance of studying the optical properties of a material is offered by the ability of this technique to provide information regarding the fundamentals gap, electronic transition, trapping levels, and localized states [10].

The optical transition witch depending on the nature of electronic transition is determined according to Tauc relation [11] given by:

$$\alpha E = B(E - E_g)^m \quad (1)$$

where α is the absorption coefficient, B constant, E_g is the energy gap and m is a constant value depends on the type of transition , where is equal to 1/2 and 3/2 for allowed and forbidden direct transition respectively, and (m) is equal to 2 and 3 for allowed and forbidden indirect transition respectively. The term E in Eq.(1) represent the photon energy which can be calculated from the relation:

$$E = h\nu = \frac{1240}{\lambda(nm)} \quad (2)$$

where h is the plank constant, ν is the incident photon frequency, and λ is the photon wavelength.

The absorption coefficient α of the optical absorption near the band edge shows an exponential dependence on photon energy $h\upsilon$ and obeys the Urbach empirical relation [12]:

$$\alpha = \alpha_0 e^{h\nu / E_e} \quad (3)$$

where α_o is a constant and E_e is the width of the localized states.

Experimental

The CdTe thin film samples were already prepared in laboratory of thin films for research in Physics Department, College of Science, Baghdad University, the preparation was done at room temperature with 300nm thickness.

A ^{137}Cs radionuclide with activity 6 mCi and dose rate of 0.5 Gy/ hr was used for exposing the samples to gamma radiation (0.662MeV) at room temperature. A set of irradiation doses were achieved by changing the exposure time and doses (10, 20, 30, 60krad)

The absorption spectra for irradiated samples were recorded using UV- Visible spectrometer in the wavelength range (300-1100) nm. The absorption coefficient was calculated using the law of light absorption: $I= I_o e^{-\alpha t}$ and accordingly $\alpha=2.303\log (I_o/I)t$ then:

$$\alpha = 2.303(\frac{A}{t}) \quad (4)$$

where I_o and I the incident and transmitted intensities, respectively, A is the absorbance and t is the film thickness [13].

In addition the absorbance spectra were used to deduce the optical constant including the refractive index (n), extinction coefficient (k) and the real (ε_1) and imaginary (ε_2) parts of dielectric constant. The reflectance (R) can be evaluated when the transmittance (T) and (A) are known from the relation:

$$A+T+R=1 \quad (5)$$

The complex refraction index (N) is given by the equation [14]:

$$N= n-ik \quad (6)$$

where n is the real refractive index, k is the imaginary part of (N) was obtained from the relation :

$$k = \frac{\alpha\lambda}{4\pi} \quad (7)$$

The refractive index was calculated by using the equation [15]:

$$(8) \quad n = \sqrt{\frac{4R}{(R-1)^2} - k^2} - \frac{(R+1)}{(R-1)}$$

The real part of dielectric constant which represents the polarization term (ε_1) and imaginary part of dielectric constant (ε_2) can be calculated from the equations [15]:

$$\epsilon_1=n^2-k^2 \quad (9)$$

$$\epsilon_2=2nk \quad (10)$$

Results and Discussion

The variation of absorbance spectra with wavelength of the investigated samples were analyzed to find out the optical band gap by using the Eq.(1), E_g evaluated from the plots of (αE) versus E as shown in Fig.(1), and determined by intercepting the linear portion of the absorption curves to the energy axis for zero absorption coefficient ($\alpha E=0$) . The results of E_g and the width of localized states are listed in Table (1). It can be seen from Fig.(1) that E_g is depending on the radiation dose where it decreased from (1.53eV) for unradiated CdTe thin film to (1.48eV) for irradiated film with dose (60krad). This result may be explained on the basis of the high dose radiation introduce energy levels in the forbidden gap which causes radical changes in the carries concentration, these new levels may be acceptor at the top of the V.B or donor levels below the C.B. This in term decreases the energy required to transport the charge carrier from the V.B to the C.B [16]. The behavior of E_g of CdTe thin films with the high doses in the present research is agreement with previous results for various thin films [12,16], as well as E_g of CdTe for unirradiated sample is in agreement to result obtained by F. Y. Al-Shakily [17]. Fig. (2) demonstrates the dependence of E_g with gamma irradiation dose. It was found the behavior of E_g generally decreases with radiation doses this is due to the radiation effect, where the exposure to the radiation increases the density of states in the gap and this contribute to make E_g narrower. However, it can be seen from this figure that E_g increases when CdTe thin film irradiated with 10 krad , this is attributed to the decreasing in the tail of the localized states will lead to increase in E_g.

Table (1): Values of E_g and E_e for CdTe thin films unirradiated and irradiated with different doses.

Irradiation dose(krad)	E_g(eV)	E_e(eV)
0	1.53	1.34
10	1.54	1.32
20	1.50	1.49
30	1.51	1.31
60	1.48	1.48

Fig. (3) shows the dependence of (lnα) with photon energy, in order to determine E_e for all samples, where they were calculated from the slopes of straight lines of lnα versus E. The results indicate that E_e increases as the radiation dose increases due to gamma irradiation of the CdTe thin films leads to the excitation of nonbonding electrons into the conduction band which has consequences in the localized states. The increase of carriers in localized states will lead to a decrease in the transition probabilities into the extended states, resulting in a reduction in the band gap. It is well known that the depth of localized states values increases with increasing the density of states introduced by the irradiation with gamma rays. The characteristics of E_g and E_e for CdTe thin films and their sensitivity with the radiation doses make it a good material for dosimetric purposes in industrial applications.

Optical Constants

The extinction coefficient (k), refractive index (n), real (ε_1) and imaginary (ε_2) parts of dielectric constant which have been estimated at λ=900nm by using equations (8), (7), (9) and (10) respectively are presented in Table (2). The variation of n as function of wavelength for unirradiated and irradiated CdTe thin films with different doses is shown in Fig (4). It was found that (n) decreased with (λ) in the range (700-1100) nm, on the other hand (n) at λ=900nm decreased from 2.35 for unirradiated film to 2.03 for irradiated film with 60 krad dose rate. It was noticed that the extremely decreasing in n value happened at highest radiation dose, indicated that the irradiated films become more transparent. Fig. (5) shows the dependence of (k) on the wavelength with deferent doses. It is evident that the behavior of k is non systematic with the increasing of gamma radiation dose, unless in the dose (60 krad), k value became smaller at the region beyond the absorption edge. The dependence of (ε_1) and (ε_2) on (λ) are shown in Figs.(6) and (7), it was concluded that the variation of (ε_1) mainly depend on the value of (n^2) because the smaller value of (k) comparison with (n^2), while the imaginary part of dielectric constant (ε_2) mainly depend on (k) values which are related to the variation of (α).

Table (2): Values of n, k, ε_1 and ε_2 for unirradiated and irradiated CdTe thin films with different doses.

Irradiation dose (krad)	n	k	ε_1	ε_2
0	2.35	0.103	5.51	0.485
10	2.20	0.083	4.87	0.367
20	2.21	0.082	4.87	0.367
30	2.25	0.088	5.05	0.397
60	2.03	0.063	4.13	0.255

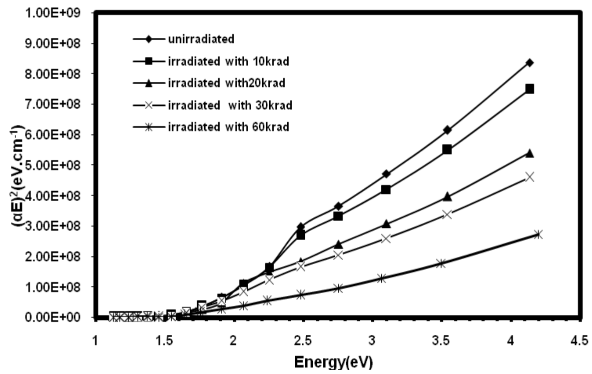

Fig. (1) The variation of $(\alpha E)^2$ versus photon energy for CdTe thin films unirradiated and irradiated with different doses.

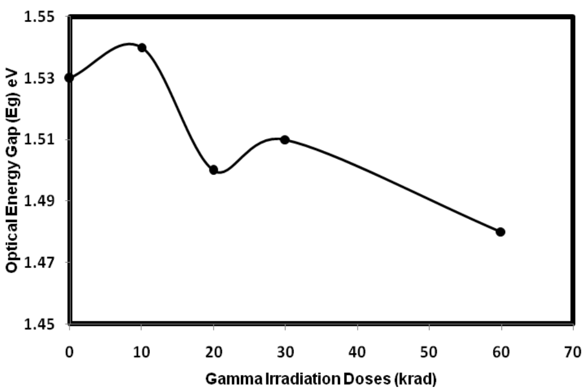

Fig. (2) Effect of the gamma irradiation doses on the optical energy gap Eg.

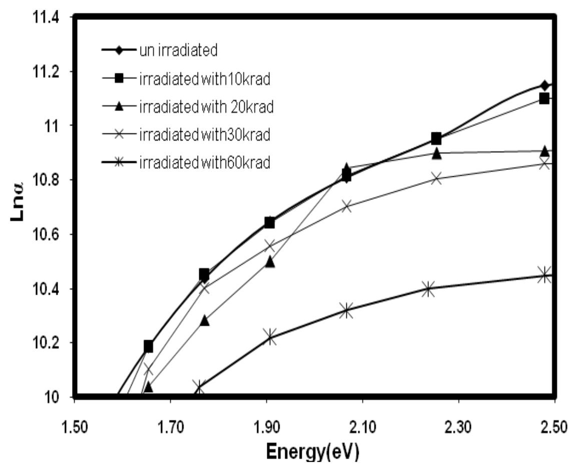

Fig.(3) The variation of (lnα) versus photon energy for unirradiated and irradiated thin films with different doses.

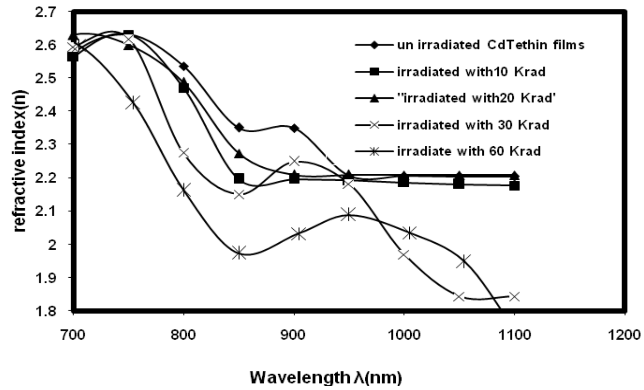

Fig. (4) The variation of (n) versus (λ) for unirradiated and irradiated CdTe thin films with different doses.

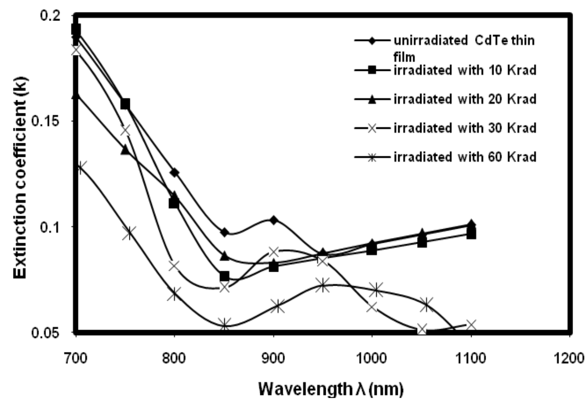

Fig. (5) The variation of (k) versus (λ) for unirradiated and irradiated CdTe thin films with different doses.

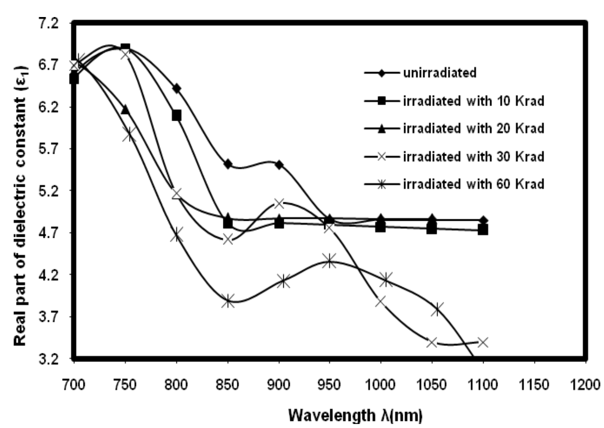

Fig (6) The variation of (ε_1) versus (λ) for unirradiated and irradiated CdTe thin films with different doses.

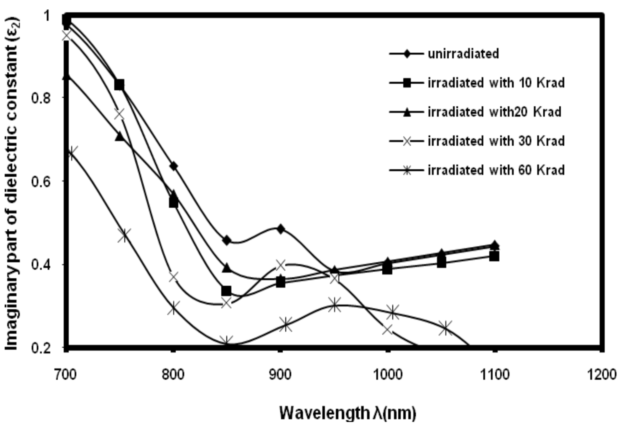

Fig (7) The variation of (ε_2) versus (λ) for unirradiated and irradiated CdTe thin films with different doses.

Conclusions

It was found that the optical properties were highly affected by the exposure to gamma radiation, such as optical energy gap values which showed a decrease in contrast to $E_e$values which showed an increase as radiation dose was increased. The values of optical constants (n, k, ε_1, ε_2) were affected obviously with the increasing of radiation dose. From the result above, it can be seen that CdTe thin films have a promising properties for using in dosimatric industrial applications.

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